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A PRELIMINARY STUDY OF MOVEMENT OF FISHES THROUGH A VICTORIAN (LERDERDERG RIVER) FISH-LADDER

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Abstract: The fish community below the spillway of a diversion weir on the Lerderderg River, Victoria and the upstream and downstream movements of fishes through a fish-ladder on the weir were studied over a seven-month period from June to December 1980. Representatives of all five species of fish recorded below the weir spillway were taken in a two-way trap installed in the fish-ladder. River blackfish (*Gadopsis marmoratus* Richardson) and brown trout (*Salmo trutta* Linnaeus) were taken most frequently. The other species taken were short-finned eel (*Anguilla australis* Richardson), Australian smelt (*Retropinna semoni* (Weber)) and roach (*Rutilus rutilus* (Linnaeus)). Mean velocity at the centre of the outflowing weir orifice was 103.9±30.9 cm/sec. Although mean water velocities within steps, 18.9-49.3 cm/sec, in the fish-ladder were not considered high, larger river blackfish and brown trout, longer than 180 mm in length, were the major users of the fish-ladder. Two alterations to existing tunnel off-take and downstream water diversion operations are suggested to increase access-time for fishes to the entrances of the fish-ladder.

Although dams are continually being constructed in Australia to provide water for domestic, industrial or irrigation purposes, relatively few of the existing barriers have fish-ways or fish-ladders incorporated (Harris 1980). Even for those barriers with some form of fish-way, little attention has been paid to monitoring the effectiveness of their design (Beumer 1980, Harris 1981). The study of Kowarsky & Ross (1981) on the Fitzroy River (Queensland) fish-ladder is the most recent and comprehensive in Australia.

The first fish-ladder to be incorporated on a barrier in Victoria forms part of the Lerderderg River Diversion Weir, approximately 45 km north-west of Melbourne. Pre-impoundment distribution studies on the fishes in the Lerderderg River suggested that at least two native species, the short-finned eel, *Anguilla australis* Richardson 1841 and the river blackfish, *Gadopsis marmoratus* Richardson 1848 and one exotic species, brown trout, *Salmo trutta* Linnaeus 1758 would be affected by construction of the weir (Beumer & Harrington 1980a).

In this paper, we report on a seven-month (June to December 1980) monitoring of the fish movement through the Lerderderg River fish-ladder and the fish community immediately downstream of the spillway and entrance of the fish-ladder.

STUDY AREA

The Lerderderg River is a 60 km long tributary of the Werribee River which flows into Port Phillip Bay (Maver & Farmar-Bowers 1979). The diversion weir is located at the lower end of a gorge section on the river. The storage area is approximately 2 ha with a capacity of about 65 ML. A series of tunnels of more than 6 km in length and a further weir on Goodmans Creek carry water from the weir into Coimadai Creek where it is stored in Merrimu Reservoir (Fig. 1). The catchment lies within a forestry reserve, the only other activity in the area being gold-prospecting.

The fish-ladder is a pool-type with full weirs and submerged alternate orifices (Fig. 2a). This design was chosen to provide a choice of passage for the different species of fish, either by migrating through an orifice or over a weir (Clay 1961). A total of 36 vertical and 6 horizontal steps form the ladder, each step being 90 cm long. A two-way trap to monitor fish movement was located at Step 36. Steps above the trap-bay are 107 cm wide while those below the bay are 102 cm wide. The weirs are 10 cm thick and each step drops 10 cm to the next. The orifices are 20 x 20 cm² in area and located 15 cm above the level of each pool base. Resting pools with a minimum depth of 20 cm are located at the right-angle bends at steps 21, 30 and 31 (Fig. 2b). All pools were normally operated at full depth with 2-5 cm of water spilling over the weirs. Discharge from the fish-ladder is at right angles to the direction of normal flow at a point level with the edge of the spillway. A compensation flow pipe, carrying water for agricultural requirements, discharges at a point level with but to the east of the fish-ladder entrance. The fish-ladder has a 1:10 slope up to and including the trap-bay and is then at a constant level to the reservoir proper.

METHODS

Weekly maximum and minimum water temperatures (°C) were recorded at three locations: (1) in the trap-bay for the entire monitoring period (24 June to 2 December); (2) above the main body of the reservoir for inflowing water and (3) 100 m downstream of the spillway for outflowing water from 7 October onwards. The height (cm) of water in the trap-bay was read from a metal rule attached to the upstream wall of the bay. Discharge figures were recorded by the State Rivers and Water Supply Commission of Victoria (S.R.W.S.C.) at O'Brien's Crossing, approximately 9 km upstream of the diversion weir.

The fish-ladder trap and the area immediately

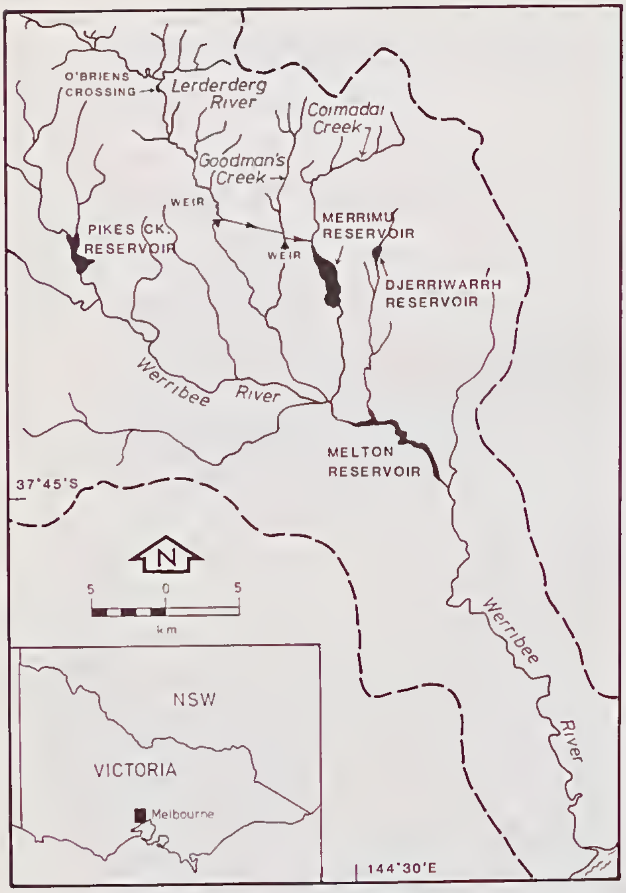

Fig. 1—Catchment area (— —) showing diversion weirs and tunnels on Lerderderg River and Goodmans Creek.

downstream of the spillway were monitored every 7 days for the occurrence and movement of fishes from 24 June to 2 December 1980, inclusive. After this date, the reservoir was drained to allow maintenance of the radial gates' control mechanism.

Two dead brown trout on the bank near the fish-ladder soon after the commencement of the monitoring led to covering the fish-ladder with a "Nylex" plastic screen of 12 mm diagonal mesh to prevent further losses. This screen was attached at a number of points in such a manner that access to steps 14, 28 and 33 could be gained readily to allow water velocities to be measured with a Teledyne Gurley flow-meter at 9 standard locations (Fig. 2a): eight within each of these steps and one in the centre of the outflowing orifice. The velocities recorded within the steps at the 8 positions were subjected to a two-way analysis of variance, using a randomised complete block design (Sokal & Rohlf 1969) where dates are blocks and step and position are factors, to test for the effects of date, step and position on the velocity. The position, open or closed, of the middle radial gate and side valves (Fig. 2b) was recorded and periods of tunnel operation were supplied by S.R.W.S.C.

The area immediately downstream of the fish-ladder entrance and below the weir spillway was electrofished with a 240 v. d.c. unit (Moore 1968) at each visit. The area, approximately 240 m^2, consisted of large boulders and a gravel substrate and had a maximum depth of 90 cm. All fishes were anaesthetised with Quinaldine, identified and measured (total length (TL) to the nearest mm). Fishes longer than 100 mm were marked below the 1st dorsal fin with small blue fingerling tags (Floy FTF-69), serially numbered with a black legend, to determine movement of individual fishes. Eels larger than 340 mm were tagged with anchor tags (Floy FD-68A). Fishes were released in the area of capture.

Movement of fishes through the ladder was monitored by a trap covered with galvanised mesh (4 mm diagonal) and installed in the trap-bay. Funnels extended from the trap into the upstream and downstream orifices of the trap-bay (Figs. 3, 4) so that all fishes would be captured. A section, 9 cm wide, was removed from the bottom of the cone of each funnel to facilitate fish entry. Guide rails were added later to facilitate movement of the funnels. Upstream and downstream catches were separated by a median division in the trap. Lids with an overhanging lip of 25 mm covered each trap section. Weights were placed on each lid to ensure a complete seal. The trap was checked every 7 days. The trap-bay was covered by a hinged steel grate and locked. All fishes were removed from the trap, handled as above, then released into the reservoir or below the spillway depending on whether these were taken in the lower or upper section of the trap respectively. For individual species, the Student's 't' test was used to determine the significance of differences between the respective mean TL of catches from below the spillway and lower trap section.

RESULTS

Both maximum and minimum water temperatures in the trap-bay were lowest during the first half of the monitoring period after which they rose to the highest values in late November (Fig. 5). Maximum and minimum temperatures in the trap-bay were significantly correlated with those recorded upstream ($P<0.01$) and downstream ($P<0.05$). Water height in the trap-bay was relatively constant except on 7 October and 2 December (Fig. 5) when the side-valves and the middle radial gate respectively were open. Discharge figures at O'Brien's crossing show peaks during early July, late August and mid-September. The middle radial gate and the side-valves were open on 13 and 3 sampling occasions respectively, while the diversion tunnel operated for a total period of approximately 20 days during late June to late September. The monthly minimum flow regime below the diversion weir instituted by S.R.W.S.C. is: 120 ML/day (May-October); 24 ML/day (November) and 60 ML/day (December-April). Of this flow, the fish-ladder carries 4 ML/day, the compensation flow pipe may release a maximum of 24 ML/day with any necessary additional flow from the side-valves and/or the middle radial gate.

Significant differences exist between velocities recorded at different positions within the steps

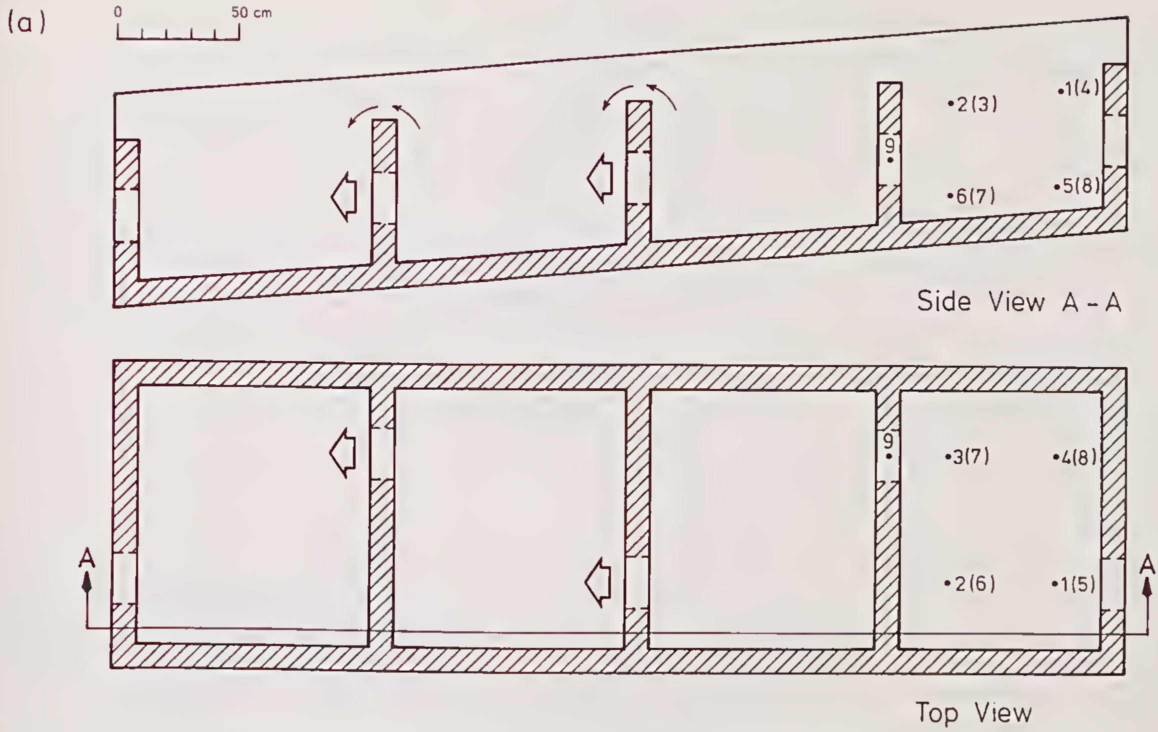

Fig. 2—a. Top and side view of four steps in fish-ladder showing positions 1-9 at which velocities measured, direction of water over weirs and through alternate orifices.

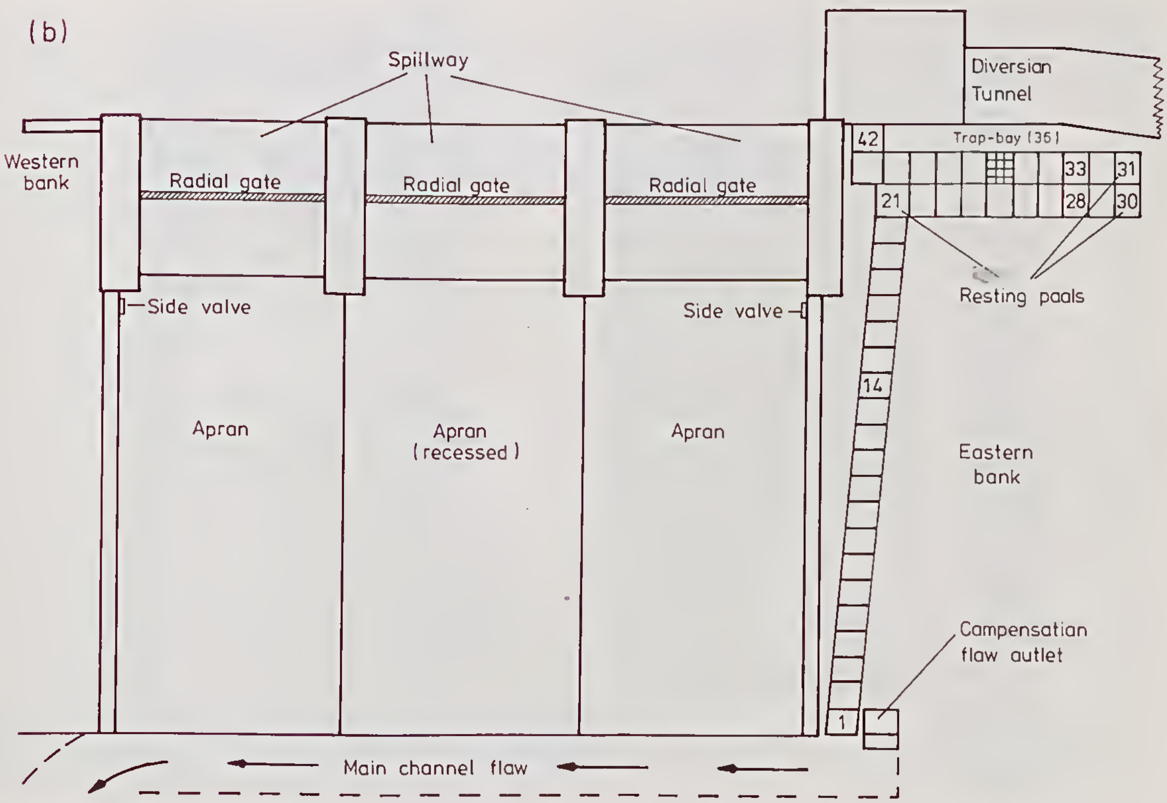

Fig. 2—b. Diagram of fish-ladder relative to diversion weir and tunnel.

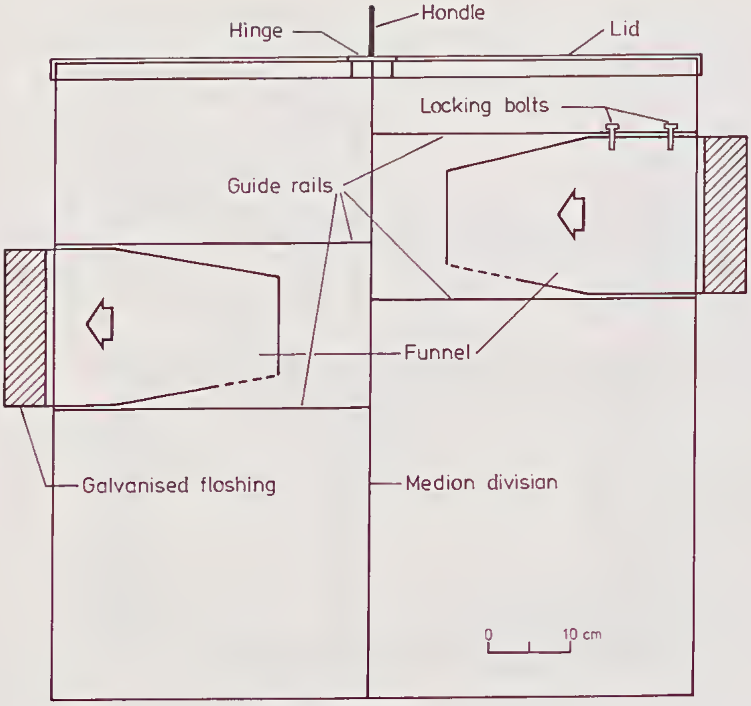

Fig. 3 — Section through two-way fish-trap used for monitoring movement in fish-ladder. Arrows show direction of flow. Lower section (— —) of cone of each funnel removed.

Fig. 4 — Two-way fish-trap, with upstream funnel on right-hand side, *in situ* in step 36 of the fish-ladder.

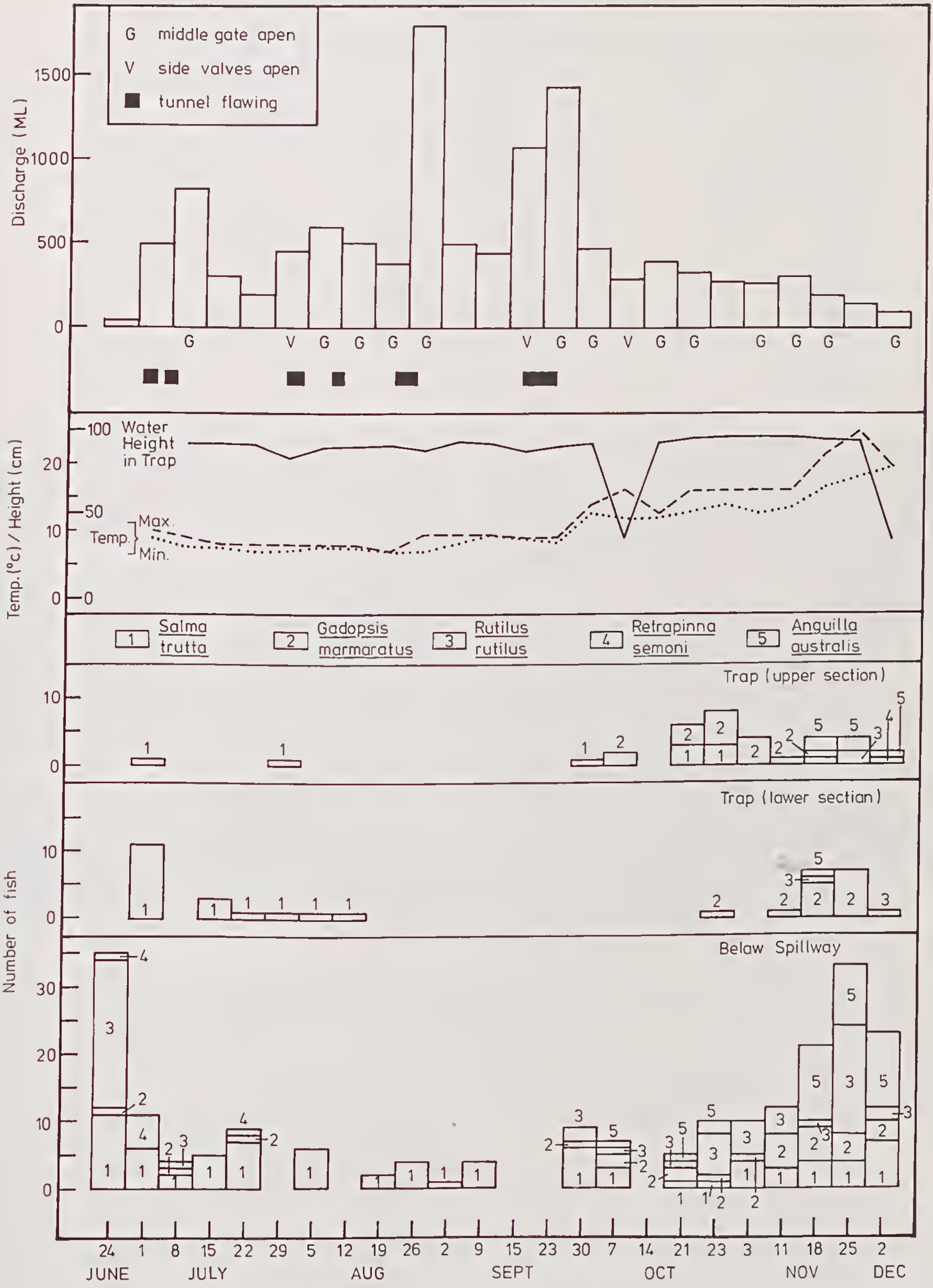

Fig. 5 — Physical parameters and abundance of fishes at the weir. Discharge recorded at O'Briens Crossing.

Table 1

Mean Velocity ± s.d. for each Position and Analysis of Variance for Effects of Date, Step and Position on Velocity

Position	1	2	3	4	5	6	7	8
Mean	49.3	20.9	18.9	39.1	43.5	29.4	28.2	25.2
Velocity (cm/sec ± s.d.)	24.1	10.4	9.9	19.5	35.3	15.3	12.4	6.4

Source of variation	d.f.	SS	MS	F
Date	16	18279.3	1142.46	3.63*
Step	2	2367.8	1183.89	3.77†
Position	7	54913.2	7844.74	24.96*
Step × Position	14	5891.0	420.79	1.34
Residual	368	115670.7	314.32	
Total	407	197122.0	484.33	

*P<0.01
†P<0.05

($P<0.01$), on different dates ($P<0.01$) and to a lesser extent at which step ($P<0.05$) (Table 1). The two highest mean velocities within the steps were at the surface (position 1) and bottom (position 5) proximal to the inflowing orifice (Table 1) while the mean velocity (103.9 ± 30.9 cm/sec) at the centre of the outflowing orifice (position 9) was more than twice any recorded within the steps.

Almost equal numbers of fishes were taken in the upper (34 specimens) and lower (35) sections of the trap during the monitoring period. Of the fishes in the trap not one was damaged. Brown trout eggs were found in the lower trap section on several occasions. Brown trout and river blackfish were the major species taken in each section of the trap, with the former species being the only one taken in the trap from June until early October (Fig. 5). In the upper section of the trap the majority of the catches was taken from mid-October onwards, with numbers of river blackfish and eels increasing as maximum temperatures rose above 15°C. In the lower section, brown trout were taken only during June to mid-August, with blackfish, roach and an eel taken from late October to early December. Below the spillway, roach, smelt and brown trout were the major species present from June to the end of September, after which river blackfish and eels became more abundant in the catches. No fishes were found in the trap-bay outside the trap.

All the brown trout taken in the upper section of the trap were longer than 210 mm TL (Fig. 6). One spent female was recorded at the end of July. None of the river blackfish, all greater than 180 mm TL, was ripe (eggs or milt freely expressed by slight pressure on the abdomen) but all were larger than the minimum spawning size of 120 mm TL (Jackson 1978). The short-finned eels, from 330 to 570 mm TL, were all immature adults with the yellow feeding body colouration. The roach taken was a juvenile.

Brown trout captured in the lower trap section (Fig. 7) were larger than those taken below the spillway on all corresponding sampling occasions. Comparison of the mean total length between below spillway and lower trap section catches for this species showed significant differences ($P<0.01$) (Table 2) for particular dates and

Table 2

Comparison of Size between below-Spillway and lower Trap Section Catches

Date	Below Spillway No.	Below Spillway TL ± s.d.	Lower Trap Section No.	Lower Trap Section TL ± s.d.
Salmo trutta				
1 July	6	129.5 ± 27.4	11	293.0 ± 31.0*
15 July	5	151.0 ± 70.2	3	369.0 ± 53.4*
1 July-12 Aug.	26	148.0 ± 46.3	18	313.3 ± 42.6*
Gadopsis marmoratus				
18 Nov.	5	210.6 ± 47.6	5	212.2 ± 26.1
25 Nov.	4	157.5 ± 64.4	7	215.7 ± 46.3
28 Oct.-25 Nov.	16	185.1 ± 48.3	14	222.4 ± 42.9†

* P<0.01
† P<0.05

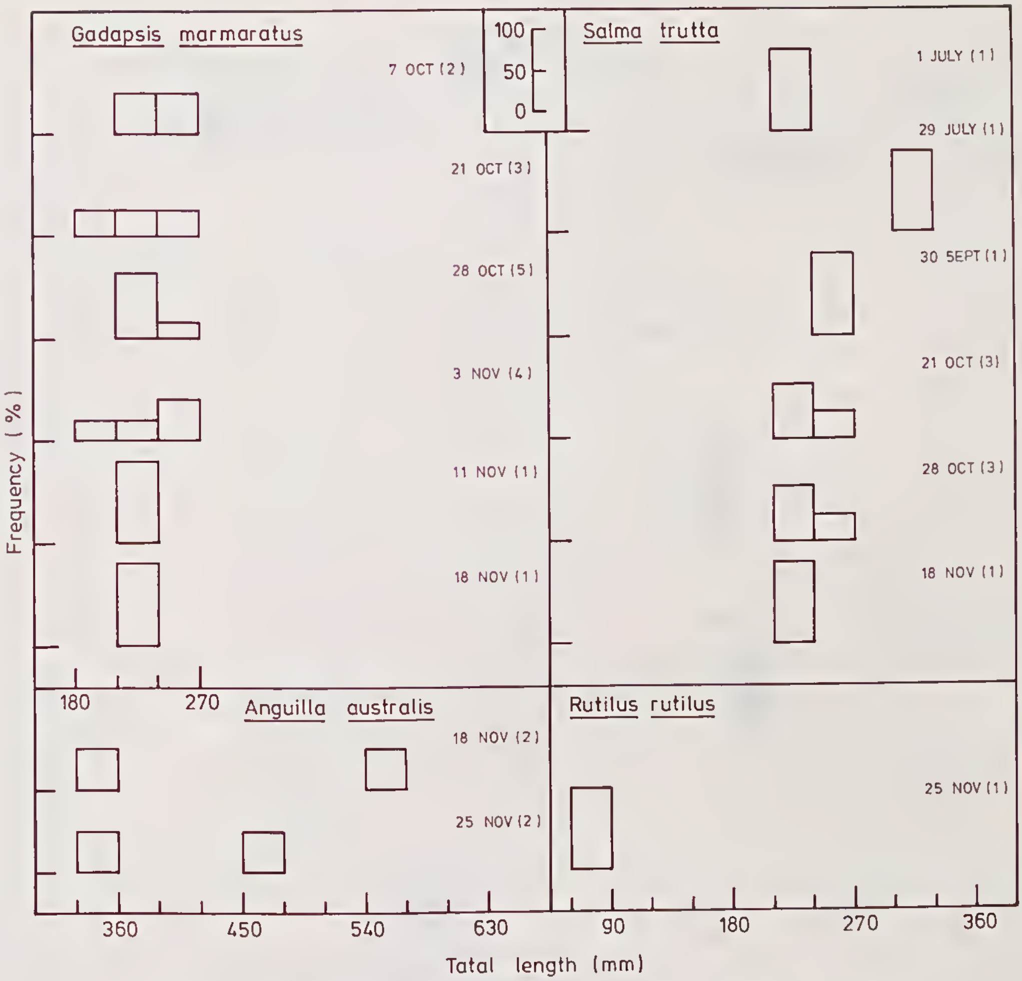

Fig. 6—Length-frequency distribution of fishes taken in the upper trap section.

for the period 1 July to 12 August. In the lower trap section, ripe males and females were present on 1 July with ripe females present during mid-July to mid-August. Brown trout taken below the spillway were juveniles or immature adults except for one ripe female taken on 15 July.

River blackfish taken in the lower trap section were greater than or equal in total length to those captured below the spillway (Fig. 8). Statistical comparison of the mean total lengths showed no significant differences for particular dates (Table 2) between the lower trap section and below-spillway samples although a significant difference ($P<0.05$) existed when the period 28 October to 25 November was considered. In the lower trap section not one of the river blackfish was ripe although all were of spawning size. Those taken below the spillway were either immature and mature adults or juveniles.

Roach larger than 90 mm were not taken in the lower section of the trap (Fig. 8) although these occurred frequently in samples from below the spillway. These samples included juveniles, immature and mature adults, and one ripe male taken on 7 October. Only one short-finned eel, a small brown elver, was taken in the lower trap section (Fig. 9). Eels taken below the spillway were brown elvers (mean $TL = 153.0 \pm 11.6$ mm; range 129-175 mm) and immature adults, again with the yellow feeding body colouration.

A total of 78 fishes was marked with fingerling tags: 39 river blackfish, 33 brown trout, 4 roach and 2 short-finned eels. A further six eels were marked with anchor tags. Of the 84 tagged fishes, 21 were recaptured once (Table 3), and three, all brown trout, were multiple recaptures. Five of the nine river blackfish recaptured were taken in the lower trap section, indicating upstream movement between 7 and 28 days after release. Four of these five fish originated from the reservoir, as these were captured initially in the upper section of the trap.

DISCUSSION

While both the number of species and specimens captured increased with elevated water temperatures during the monitoring period, the correlation between inflowing water temperatures and fish-ladder temperatures and also between fish-ladder temperatures and outflowing water temperatures suggest that the shallow

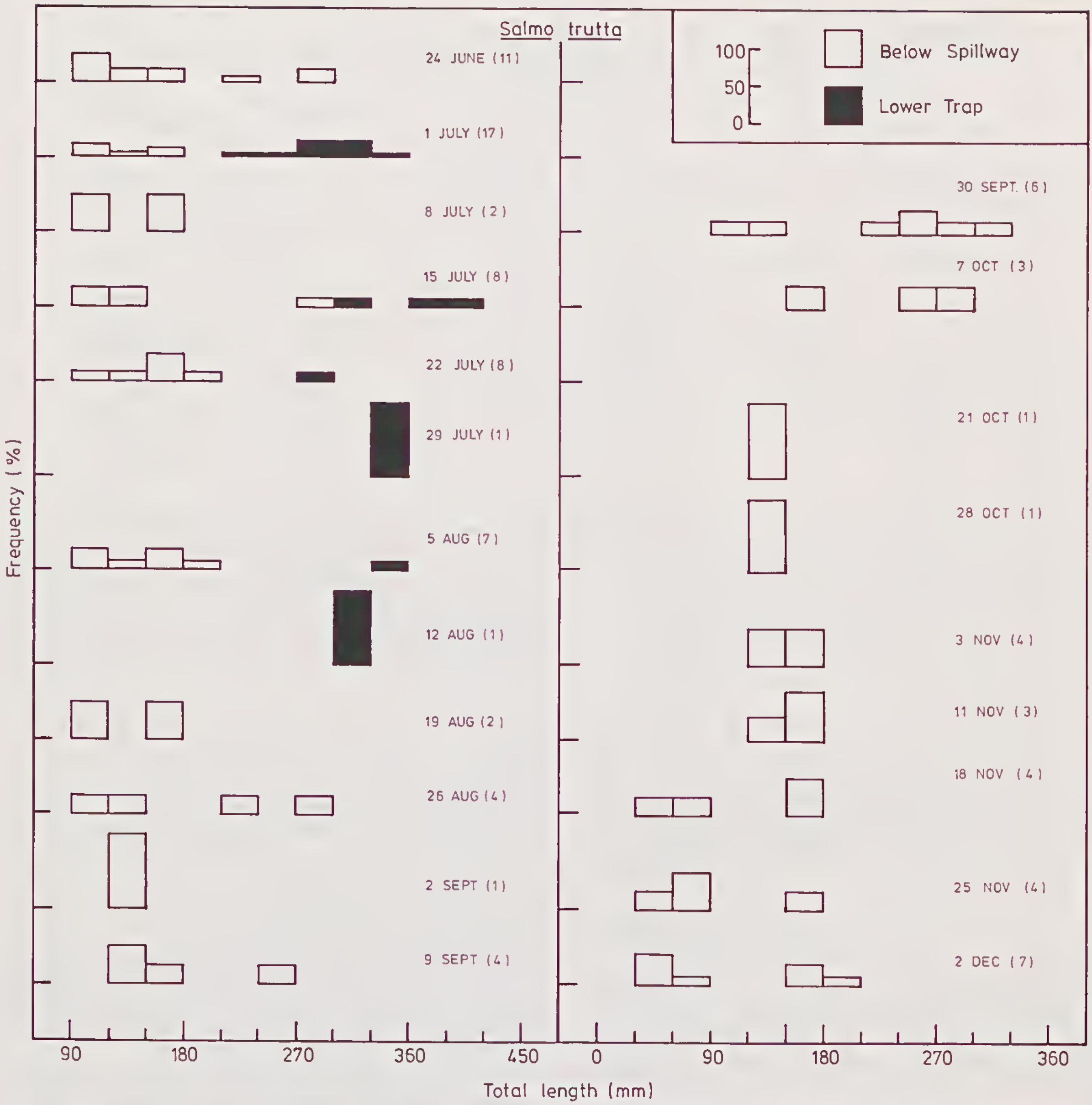

Fig. 7—Length-frequency distribution of brown trout, *Salmo trutta*, in the lower trap section and below the spillway.

reservoir does not alter the normal temperature regime of the Lerderderg River. Furthermore, fish behaviour within the river is not disrupted by fluctuations in temperature which are often associated with deeper and larger reservoirs, e.g. Dartmouth Dam (Blyth 1980) or with diversion operations. Fishes were affected by fluctuations in discharge with reduced catches related to peaks of discharge. This is due to a combination of decreased density of fishes and their displacement at times of increased water volume and to a lesser extent to the reduced visibility and consequent lower efficiency of electrofishing operations in rapidly flowing turbid waters.

The fish-ladder design permits larger brown trout and river blackfish to migrate upstream and downstream. Movement through the fish-ladder may be random, as suggested by some of the recapture data for river blackfish, or be specific as recorded for brown trout captured on upstream spawning migrations. Short-finned eels, roach and smelt did not utilise the fish ladder to the same extent. This may reflect the unsuitable velocity or the time of sampling. However, Davidson (1949) found an average swimming speed of 60.8 cm/sec for specimens of *Anguilla rostrata* Lesueur of a size similar to that of the brown elvers recorded here. This speed is higher than that recorded in any of the eight positions within a step. Sorensen (1951) found eels, *A. anguilla* Linneaus, 100-150 mm TL, capable of migrating upstream at water temperatures of 20°C against currents of between 90 and 130 cm/sec, speeds

Fig. 8—Length-frequency distribution of river blackfish, *Gadopsis marmoratus*, and roach, *Rutilus rutilus*, in the lower trap section and below the spillway.

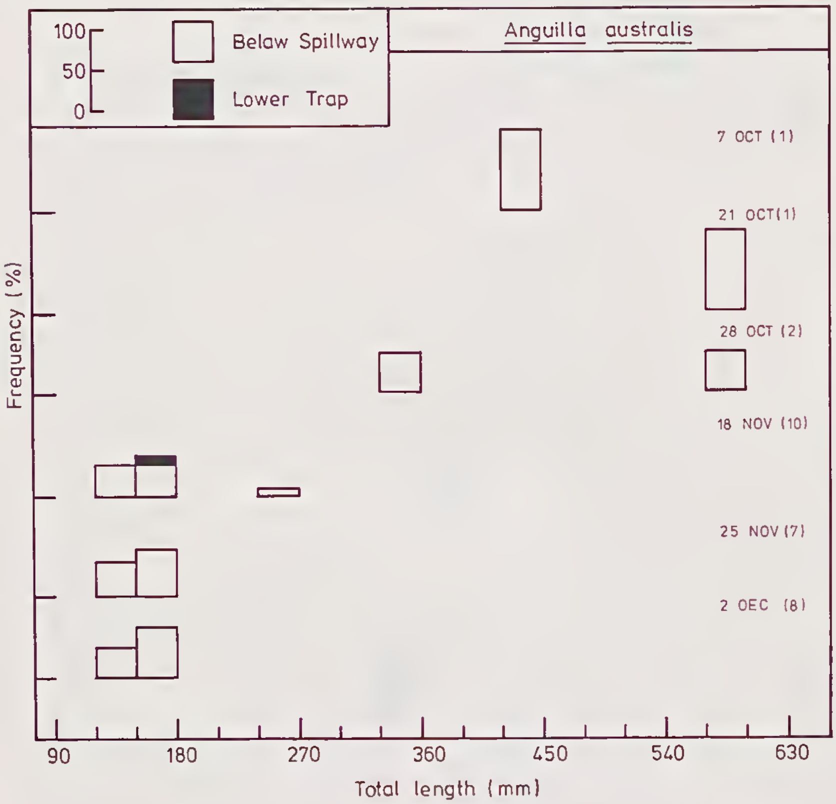

Fig. 9—Length-frequency distribution of short-finned eel, *Anguilla australis*, in the lower trap section and below the spillway.

within the range recorded in this study. The migration of short-finned eels, *A. australis*, is temperature dependent and follows a period of dormancy in winter (Beumer 1979). The upstream movement of the brown elvers follows a spring-summer pattern (Beumer & Harrington 1980b) and the results suggest this movement was just commencing when the monitoring period ended.

Although apparently suitable for larger brown trout and river blackfish, the fish ladder was not shown to be utilised by small individuals of either species. Studies of other fish species have shown that larger individuals are capable of swimming against velocities equivalent to those recorded here, especially when in peak condition (Farlinger & Beamish 1978). Even though these velocities may be high in certain sections of the fish-ladder, e.g. greater than 100 cm/sec through the outflowing orifice of a step, several factors, including the size of the brown trout and river blackfish, the relatively short distance over which these velocities extend and the presence of significantly lower velocity backwater regions in the steps, reduce the energy expenditure of fishes migrating upstream. The mean velocities recorded at all eight positions within the steps are below the threshold value of 60 cm/sec above which rheotactic coastal off-shore fishes (mean length range 30-60 mm) are displaced downstream (Schuler & Larson 1975). Furthermore, studies on marine fishes have shown burst swimming speeds of more than 100 cm/sec for one second (Dorn *et al.* 1979) and, assuming that the fishes in this study have similar swimming capabilities, the velocities recorded within the study may be within their capacity and allow upstream migration if made over an extended period. Successful swimming performances of fishes require high ambient oxygen levels (Kutty & Saunders 1973) and are temperature-dependent (Otto & Rice 1974). The oxygen levels, although not measured in this study, are assumed to be non-limiting as a result of high mixing and turbulence of the water while passing down through the orifices and over the weirs of the fish-ladder. An increase in swimming performance with increasing temperature has been recorded for certain species of freshwater fish (Otto & Rice 1974). The increase in numbers of fishes, both below the spillway and in the trap in the latter half of the monitoring period, as a result of increasing activity may in part reflect a similar performance for fish species in the Lerderderg River.

Reasons for the limited use of the fish-ladder by smaller fishes are uncertain. While the possibility of escape by returning upstream or downstream from the trap or by escape through the mesh (4 mm diagonal, 2.83 mm square) should not be discounted, several factors suggest that this would be minimal. Fishes actively migrating upstream do so in response to and by orientating into the downstream-flowing current. The absence of fishes in the trap-bay outside the trap and the body-depth (≥ 5 mm) of brown elvers (≥ 100 mm TL) suggested that there was no escape from the trap through the mesh. While the extent of escape was not evaluated, it is assumed that the opportunity to escape through the funnels would be equal for all species and

TABLE 3

RECAPTURE DATA FOR EACH SPECIES OF FISH IN 1980

Unless indicated, release and recapture sites are below diversion weir spillway.

Species	TL (mm)	Release Date	Recapture Date(s)
Gadopsis marmoratus	185[a]	3 Nov.	25 Nov.[b]
	202[a]	28 Oct.	25 Nov.[b]
	239[a]	11 Nov.	25 Nov.
	250[a]	3 Nov.	25 Nov.[b]
	262[a]	28 Oct.	18 Nov.[b]
	165	28 Oct.	18 Nov.
	252	7 Oct.	21 Oct.
	254	3 Nov.	18 Nov.
	266	18 Nov.	25 Nov.[b]
Anguilla australis	585	21 Oct.	28 Oct.
Rutilus rutilus	165	30 Sept.	28 Oct.
	196	30 Sept.	21 Oct.
Salmo trutta	103	5 Aug.	19 Aug.
	118	26 Aug.	3 Nov./18 Nov./25 Nov./2 Dec.
	125	9 Sept.	30 Sept.
	134	2 Sept.	9 Sept./21 Oct./28 Oct.
	145	3 Nov.	18 Nov.
	157	19 Aug.	9 Sept.
	158	3 Nov.	11 Nov.
	247	30 Sept.	7 Oct.
	275	26 Aug.	30 Sept./7 Oct.

[a] initially captured in upper trap section.
[b] recaptured in lower trap section.

the recorded catches in the trap still reflect the migrating trends and fish-ladder usage. Some fishes 100 mm TL or smaller are able to attain speeds of 25 body lengths/sec (Wardle 1975) and the recorded water velocities of this study are within this limit. Smaller brown trout, river blackfish, roach and smelt may not make upstream migrations similar to those of larger, more mature individuals but rather utilise the area below the spillway as a suitable habitat. Alternatively, smaller individuals of these four species may be incapable of attaining the required speeds or be inhibited from entering the fish-way by the presence of larger individuals.

As with other fish-ladders (Sakowicz & Zarnecki 1962, Dominy 1973, Kowarsky & Ross 1981) and their capability to allow fishes to pass, a number of problem areas exist with the Lerderderg River ladder. Possible modifications to the design of the fish-ladder to improve its effectiveness by reducing velocities and turbulence include bevelling each orifice on both sides (top and bottom only) or, at least, on the entry side, and the inclusion of a slot in each weir in such a manner that the flow passing through the fish-ladder forms two intersecting sinusoidal lines (Sakowicz & Zarnecki 1962). The capacity of the fish-ladder and compensation pipe combined provide the required downstream flow for only one month (November) each year. For the rest of the year, the middle radial gate and/or the side-valves must be opened and this may divert the upstream migrating fishes away from the fish-ladder entrance. A possible solution is the controlled release from the three radial gates in such a manner as to extend the area and intensity of the velocity of release water from the fish-ladder entrance outwards. However, the current operating mechanism for these gates allows only for releases from the middle gate (to an initial maximum opening of 45 cm) before the two outer gates may be opened. It is unlikely that species other than short-finned eels would make their way upstream over the spillway. A screen placed along the lower spillway margin to guide fishes to the fish-ladder entrance may partly resolve this situation. Fishes, originating from the reservoir, have also been caught between the bottom of the middle gate and the spillway (K. Long, S.R.W.S.C. pers. comm.) when water was released from the reservoir. No further fish were found outside the fish-ladder after its covering with the Nylex screen. The screen also prevented leaf-litter and other extraneous material from entering the fish-ladder, thereby reducing maintenance.

Operational procedures for the diversion of water through the tunnel may also result in physical displacement of reservoir and migrating fishes to Goodmans Creek partly because of the proximity of the fish-ladder intake to the tunnel entrance. The present procedure of diverting the entire volume of the reservior above the fish-ladder intake level when full results in extreme fluctuations of reservoir level over a relatively brief period. A gradual continual removal of excess water above the intake level of the fish-ladder would allow more stable reservoir water levels and a standard head of water acting on the upstream entrance of the fish-ladder. In addition this would allow the maintenance of flows through the fish-ladder in summer and autumn when fishes with temperature-dependent swimming performances and behaviour patterns may by-pass the diversion weir. Further monitoring with the trap at these times would provide evidence of seasonal movements by fishes and may also be of use in controlling the invasion of the reservoir and upper reaches of the catchment by undesirable species of fish, e.g. common carp, *Cyprinus carpio* Linnaeus 1758, already established in the Melton reservoir.

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